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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AN OUTLINE FOR A GRADUATE LEVEL COURSE IN R&D MANAGEMENT

Management Analysis and University Programs Office

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Preface

This outline for a graduate course in Research and Development Management was originally developed for use by the Political Science Department of Purdue University. The idea for a course developed by practicing professionals grew out of conversations between Philip H. Whitbeck, Director of Administration at the Manned Spacecraft Center and Professors Boyd R. Keenan and Don E. Kash of Purdue.

Based in part on the Purdue experience, the outline was revised and distributed to over a dozen colleges and universities for possible assimilation of the materials in existing courses, or to aid in developing new courses in topic areas such as R&D Management, Science and Public Policy, or The Administration of Science.

The outline was prepared by the Management Analysis and University Programs Office of the Manned Spacecraft Center. Earle B. Young, Chief of the office, was the project leader. He was assisted by Richard E. Stephens, James R. Fulton, Neil Thueson and William N. Henderson.

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TABLE OF CONTENTS

I. THE R&D INDUSTRY

A. Definition

Research and development has been defined in many ways by many people. It would be appropriate to look at some of these.

David Novick of the RAND Corporation classifies R&D into four steps.

Step I - Basic research, experimental research, basic development.

Step II - Applied research, advanced development, basic evaluation, basic testing.

Step III - Product development, product testing, product evaluation, pilot production.

Step IV - Product application, application research, applied testing, applied evaluation.

Other definitions include:

1. Edward B. Roberts, The Dynamics of Research and Development, Harper and Row, Publishers New York, 1964.

2. Cornelia & Bergen Evans, Dictionary on Contemporary America Usage.

3. Merle A. Tuve, Symposium on Basic Research, American Association for the Advancement of Science, 1959.

All of these definitions tend to stress the need for classification rather than lumping all unique study as research.

The role of all facets of the U.S. in research activities and the tremendous impact of the Federal Government give R&D type projects and funding a foremost place in the American way of life.

Other areas to be discussed in arriving at a final definition of R&D:

1. Basic research

2. Applied research

3. Engineering development

4. Engineering evaluation

5. Scientific thought

6. Invention

7. Discovery

In other words the reader or student made a wide realm of study to decide the appropriate reference for R&D.

B. Historical Analysis

1. To World War II

R&D is found prior to World War II only on a very small scale and with specific characteristics.

a. Individual research carried out by intellectuals in such basic fields as chemistry, biology, engineering and generally directed toward a specific goal. Today this would be classified as applied research. DeVinci, Galileo, Currie, Pasteur, etc., all were early researchers. Later research, as the impact of the U.S. began to grow, included small weapon development; firearms; ammunition, etc.

b. Industrial R&D in the early part of this period was almost nonexistent except as related to areas of the individual research. As the industrial areas of the world began to grow the need for technological improvement became a prime factor in "profit". New time-saving items gave one company an edge over the other.

c. Governmental R&D was also keyed to a low level. Mainly in weapon development and such items that could have military applications such as airplanes.

d. University - again the individual researcher.

2. Since World War II

a. Industrial Research

(1) Giant industries: drugs, retail manufacturers (G.E., Westinghouse, etc.) characterized by applied research coupled with consumer characteristics.

(2) Military: including non-profits, inhouse, and the big impetus to R&D--governmental grants and contracts.

(3) University: in addition to the existing individual researcher; universities came to participate in all aspects as subcontractors to the industrial and governmental organizations.

(4) Other governmental: such varied subjects as aircraft, agriculture to zoology, became subject for governmental research organizations.

3. Factors Affecting Growth

a. Defense needs - war, threats of war, prevention of war, keeping the peace.

b. Current status of world civilization--big things cost big money--such a project as Apollo could not have been funded prior to World War II even if the knowledge had been there. The GNP has kept pace with technology while other things lag.

c. Desire of the public - leisure time and the impressionable consumer.

d. Need for maintaining an image.

(1) Weapon

(2) Space

4. Peculiar Dynamics of R&D

a. Size - large and growing on the surface.

b. Life cycles of products seem to shrink both in defense and non-defense item.

(1) Defense - other nations are achieving increased capability.

(2) Non-defense - tickle public.

5. Summation

Massive R&D is a new concept in terms of world history and is possible only today because we have the resources to marshal toward gigantic projects.

II. THE ORGANIZATION OF RESEARCH AND DEVELOPMENT EFFORT IN THE EXECUTIVE BRANCH

A. Introduction

1. Federal Government was formed by men like Franklin and Jefferson who held science in high regard, but early effort was performed by scattered offices.

    a. Naval Observatory

    b. Coast Survey

    c. Corps of Topographical Engineers

    d. Smithsonian Institution (1846)

    e. National Academy of Sciences (1863)

    f. Department of Agriculture established and Morrill Act (land grant colleges) passed in 1862.

2. Steady growth in post-Civil War period

    a. Agencies expanded their activities

        (1) Army began medical research and experimental signal activities.

        (2) National Bureau of Standards began analysis and testing.

        (3) Data gathering services expanded

            (a) Coast and Geodetic Survey

            (b) Weather Bureau

            (c) Census Bureau

    b. Early attempt to coordinate Federal activity

        (1) Joint Congressional Committee (Allison Commission, 1884-1886) was named to study scientific activity.

        (2) It was decided research activity should permeate the Federal structure rather than being centralized.

3. World War I

    a. National Advisory Committee for Aeronautics established to do aeronautical research.

    b. Congress created National Research Council as an extension of the National Academy of Sciences for furnishing advice and counsel to the government.

4. Between the wars, the following government labs and research institutes were established:

    a. The Naval Research Laboratory, 1923

    b. National Institutes of Health, 1930

    c. Science Advisory Board, 1933

    d. Agricultural Research Center, 1934

    e. National Cancer Institute, 1937

    f. National Defense Research Committee, 1940

5. World War II to the Present

    a. Office of Scientific Research and Development (OSRD) was organized to meet wartime requirements. (Dr. Vannevar Bush)

        (1) National Defense Research Committee incorporated

        (2) Committee on Medical Research created

        (3) Manhattan Engineer District created for atomic bomb development

    b. National Science Foundation

        (1) Proposed in 1945 report, <u>Science, The Endless Frontier</u>, by Dr. Vannevar Bush, head of OSRD.

        (2) Established by Congress in 1950

    c. President's Scientific Research Board

        (1) Established in 1946 under chairmanship of Dr. John R. Steelman.

        (2) Recommended establishment of Interdepartmental Committee for Scientific Research and Development.

d. Office of Science and Technology

(1) First created in 1951 as Science Advisory Committee in Office of Defense Mobilization.

(2) In 1957 it was reconstituted as the President's Science Advisory Committee (PSAC) and transferred to the White House Office.

(3) The President created the position of Special Assistant for Science and Technology to act as PSAC Chairman.

(4) In 1959 the Federal Council for Science and Technology was created, succeeding the Interdepartmental Committee.

e. New agencies

(1) Atomic Energy Commission created to assume control of nuclear research from Manhattan Engineer District.

(2) Separate military services were reorganized into Department of Defense.

(3) National Aeronautics and Space Administration (NASA) created in October 1958.

B. The Organization of R&D Today

1. Advisory bodies in the Executive Office of the President

a. The Office of Science and Technology

(1) Directed by Special Assistant to the President for Science and Technology.

(2) Special Assistant also serves as Chairman of PSAC and the Federal Council.

(a) PSAC composed of 18 eminent scientists and engineers from private life. Advises President, Cabinet, and National Security Council.

(b) Federal Council composed of agency heads or high level officials to advise, plan, and coordinate.

b. The National Aeronautics and Space Council

(1) Advises and assists President in developing a comprehensive program.

(2) Chaired by Vice President and consists of Secretary of State, Secretary of Defense, Administrator of NASA, and Chairman of Atomic Energy Commission.

c. The Bureau of the Budget

(1) Involved in planning and management of government-wide R&D activities.

(2) Reviews budgets for all R&D activity.

2. Organizations engaged principally in research

a. National Academy of Science - National Research Council (quasi-governmental).

(1) Established under Congressional charter to advise the government. About 600 members elected for their research accomplishments.

(2) Research Council composed of about 300 appointed by President of the Academy to insure a broader representation of scientists and engineers.

(3) Activities

(a) Sponsors conferences and symposia.

(b) Sponsors collection and publication of scientific data and research.

(c) Administers public and private funds for research projects and fellowships.

b. National Science Foundation

(1) Has a role of leadership, planning, and assistance.

(2) Supports three contractor-operated research facilities:

(a) Kitt Peak National Observatory.

(b) National Center for Atmospheric Research.

(c) National Radio Astronomy Observatory.

c. Smithsonian Institution

(1) Conducts research and disseminates scientific knowledge as well as operating national museums.

(2) Conducts research at Astrophysical Observatory at Harvard.

(3) Operates satellite tracking network (12 stations).

3. The principal agencies with large research and development expenditures

a. The Department of Defense

(1) The Office of the Secretary of Defense (OSD) concentrates R&D effort in office of the Director of Defense Research and Engineering (DDRE).

(a) Reviews and approves all R&D from the three armed services.

(b) Advises Secretary of Defense on planning and program development.

(c) Supervises Advanced Research Projects Agency (ARPA) which engages in R&D effort.

(2) The Assistant Secretaries for Research and Development direct and control all R&D activities within their respective departments.

(a) R&D Organizations in the Department of the Army.

_1_. Chief of Research and Development.

_2_. Army Research Office.

_3_. Electronics Command.

_4_. Missile Command.

(b) R&D Organizations in the Department of the Navy.

_1_. Office of Naval Research.

_2_. Chief of Naval Material.

_3_. Air, Ordnance, and Electronic Commands.

(c) R&D Organizations in the Air Force.

1. Chief Scientist.

2. Deputy Chief of Staff for R&D.

3. Office of Aerospace Research.

4. Systems Command.

5. Space Systems Division.

6. Ballistic Systems Division.

b. The Atomic Energy Commission.

(1) Organized to assume civilian control of atomic energy after World War II.

(2) Entire agency may be called an R&D organization since its aim is to develop nuclear technology for both military and civilian applications.

(3) Three Assistant General Managers have primary research and development responsibilities.

(a) Assistant General Manager for R&D.

1. Program direction for all R&D of civilian applications except reactors.

2. Supported by five headquarters divisions.

3. Has direct supervision of Brookhaven National Laboratory.

4. Has program direction of most AEC laboratories, including Argonne, Oak Ridge, and Sandia.

(b) Assistant General Manager for Reactors.

1. Responsible for development of reactors for civilian, space, and naval applications.

2. Admiral Rickover heads Naval Reactors Division and supervises the Bettes' and Knolls' Atomic Power Laboratories.

3. Space Nuclear Propulsion Office (a joint office with NASA) develops reactors and rocket engines.

(c) Director, Division of Military Applications

1. Supervises all R&D of nuclear weapons.

2. Supervises Los Alamos Scientific Laboratory and Lawrence Radiation Laboratory.

c. National Aeronautics and Space Administration.

(1) Responsible for manned and unmanned scientific exploration of space, development of required technology, and development of operational capability.

(2) Entire agency is devoted to R&D and contract management effort.

(3) Office of Advanced Research and Technology (OART) develops basic technology required.

(4) Office of Space Science and Applications (OSSA) is responsible for unmanned scientific satellites and spacecraft and development of systems for commercial applications.

(5) Office of Manned Space Flight develops launch vehicles, spacecraft, and ground systems and conducts space operations.

d. The Department of Commerce.

(1) Departmental R&D effort has increased considerably in recent years and will expand even more if Congress passes the Oceanography Bill.

(2) Most R&D effort is concentrated under the Assistant Secretary for Science and Technology, who supervises the Patent Office, Bureau of Standards, and the newly created Environmental Sciences Service Administration (ESSA).

(a) ESSA is comprised of four agencies: Weather Bureau, Coast and Geodetic Survey, National Environmental Satellite Center, and the Environmental Data Service.

(b) ESSA will make considerable use of various applications satellites developed by NASA.

(c) ESSA may develop deep-ocean research vessels if Congress approves Oceanography Bill.

(d) ESSA also plans four Institutes: Oceanography, Earth Sciences, Atmospheric Sciences, and Aeronomy.

e. Nuclear Power and Propulsion: An example of multi-agency cooperation.

(1) Atomic Energy Commission has primary responsibility for all nuclear reactor developments.

(2) NERVA engine and NRX reactor being jointly developed in program managed by Harold B. Finger, who holds positions in both AEC and NASA.

(3) Nuclear ramjet program (Project Pluto) is joint effort of AEC and Air Force.

(4) Air Force and NASA personnel work with AEC for development of Space Nuclear Auxiliary Power (SNAP) systems.

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Committee on Armed Services, House of Representatives.

Joint Committee on Atomic Energy.

Committee on Aeronautical and Space Sciences, U.S. Senate.

Committee on Armed Services, U.S. Senate.

III. THE DECISION-MAKING PROCESS IN THE FEDERAL GOVERNMENT

A. Introduction

1. The process of decision-making in the Federal Government is often a long, arduous one. The diffusion of power and authority purposely makes it so in order that all factors may be duly considered and that all sides may be heard.

2. Exceptions to this rule have been those programs of high-national priority, such as the atomic bomb and space programs.

3. Decisions are made at many levels, although principally at the levels of the agency head, the Chief Executive, and the Congress. Decisions can be made in an infinite variety of situations, varying from broad policy decisions and the approval of multi-billion dollar high-priority programs or the approval of small projects.

4. The budget approval cycle generally serves as the decision-making vehicle, although many important decisions are made independently of budget timing.

B. Types of decisions made in departments and agencies

1. Often fierce competition within an agency, i.e., missile development.

   a. Air Force, Army, and Navy were engaged in early missile (IRBM) development.

   b. Each service struggled fiercely to maintain its role.

   c. Department of Defense ended struggle by assigning ICBM's to Air Force, tactical missiles to the Army.

   d. The Navy was given the Polaris missile program.

2. Decisions must be made regarding rival technologies.

   a. Curtailment of manned bomber production (B-70) in deference to reliance upon ICBM's.

3. Decisions must be made whether or not to continue expensive systems developments based on potential requirements for and benefits from the system.

   a. Dynasoar (X-20), an Air Force manned spacecraft, was cancelled because requirements and benefits were questionable.

b. Nike-X, the anti-missile program, is currently suspended because of uncertainty as to whether its cost of many billions would be justified by its effectiveness.

C. Decisions to be made by the President

1. Approval of all decisions made by agency heads.

2. Development of all agency plans into the Administration's program and budget for presentation to the Congress.

   a. Bureau of the Budget serves as the President's staff office for formulation and analysis of the budget; advises and recommends on budgetary matters.

3. The Special Assistant to the President for Science and Technology, the President's Science Advisory Committee, the Federal Council for Science and Technology, and the National Aeronautics and Space Council advise and make recommendations to the President on scientific and technical matters.

4. On matters of prime importance considerable liaison takes place with the appropriate Congressional leaders and committees before programs are submitted.

   a. The recent discussion regarding the future of America's space program is an example of the activity which takes place at this time.

   b. The administration must decide whether or not to continue both the Air Force's and NASA's space programs. Since NASA's multi-billion dollar capability will hardly be moth-balled, then it must be decided what goals will be established for NASA following the lunar landings.

   c. The Space Council and the House Space Committee both conducted a series of extensive hearings in order that all opinions could be heard and evaluated.

D. Congressional Approval

1. Generally large programs have tacit approval of Congressional leaders before the budgets containing programs come to the Congress.

2. The big policy decisions which resulted in new agencies:

   a. Civilian control over atomic energy--resulted in the Atomic Energy Commission being created to assume from the Army the responsibility for developing nuclear technology for military and civilian application.

b. Unification of the military services, which implied centralized control over R&D--resulted in the creation of the Department of Defense and the Director of Defense Research and Engineering.

c. Civilian control over the exploration of space for peaceful purposes--resulted in the creation of NASA.

(1) Incorporated National Advisory Committee for Aeronautics.

(2) Incorporated Development Operations Directorate of Army Ballistic Missile Agency (Von Braun's group).

(3) Relied upon Air Force for launch vehicles for Mercury and Gemini Programs.

d. These policy decisions by the Congress originated from sources within both the Executive and Legislative branches and from private sources outside the government, and were generally preceded by considerable discussion in the press and journals and at conferences and symposia.

e. Many times, however, Congressmen differ on certain projects, especially in the military area when large dollars amounts and vital questions of national security are at stake.

(1) Airplanes vs. battleships

(2) Missiles vs. bombers

(3) Liquid vs. solid rocket propulsion

(4) Nuclear vs. conventional-powered aircraft carriers

(5) Basic vs. applied research programs

E. Extra-governmental influences on the decision-making process are significant.

1. From the aerospace and other industries heavily involved in R&D and defense hardware.

a. "Selling" ideas to agencies

b. Lobbying through Congress

2. From the scientific community

   a. Through advisory and ad hoc committees

   b. Through universities already heavily involved in government funded research.

3. From local political and civic groups working through their Senators and Representatives, seeking contracts or facilities for their region or city.

4. Large, well-organized lobbying groups such as the U.S. Chamber of Commerce and the labor unions that are very active for or against programs, according to how they affect the members of their groups.

5. Lobbying groups, as long as they operate legally and ethically, are an essential part of the democratic process by which the views of the citizens are brought to bear on current issues. The public administrator, especially the technical man, must recognize this activity as part of the environment, the "real world" in which he operates, and not become overly resentful of the system when decisions which are essentially technical are decided wholly or partially upon socio-political economic grounds rather than upon "the facts" as he sees them.

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IV. THE ROLES OF TECHNICAL AND NON-TECHNICAL PEOPLE IN THE FORMULATION AND EXECUTION OF PUBLIC POLICY

A. The "scientific" revolution is a continuation of the "industrial" revolution.

1. As increasing complexity requires greater innovation, more emphasis must be placed on R&D instead of production.

2. Increasingly science has played greater roles in economy, military preparedness, and competition for prestige between nations.

3. Large-scale entry of government into R&D brought the concomitant need for advice and judgments of scientists over a wide range of important policy decisions.

4. As a result of this, scientists and engineers play a significant role in policy formulation.

   a. Scientists and engineers occupy many executive positions in government agencies, i.e., Dr. Harold Brown, physicist, former Director of Defense Research and Engineering, now Secretary of the Air Force.

   b. Most agencies have scientist advisors and scientific advisory committees.

      (1) Atomic Energy Commission has a General Advisory Committee.

      (2) Department of Defense has the Defense Science Board.

      (3) NASA has the National Academy of Sciences Space Science Board.

      (4) Air Force has a Chief Scientist and a Council of Air Force Scientists.

B. Examples of technical advice influencing decisions

1. President's Science Advisory Committee (PSAC).

   a. Nuclear Weapons Testing: U.S. entered test ban talks at Geneva, but additional study discovered that technical basis of monitoring system was inadequate.

   b. Nuclear Power Airplane: PSAC recommended against crash program on the basis of inadequate reactor technology.

c. B-70 supersonic bomber: PSAC advised against production on the grounds that missiles were cheaper, speedier, and less vulnerable means of delivery.

2. Direct appeal to Congress on the matter of nuclear testing, 1954-1956.

   a. As a result of considerable dissent among scientists and the AEC, the Joint Committee on Atomic Energy held hearings in 1956.

   b. AEC information policies and facts were criticized and disputed.

   c. Complaints of scientists emerged as a political proposal in 1956 campaign of Adlai Stevenson.

   d. Arguments centered around military strength vs. genetic damage and deaths (Teller vs. Pauling).

C. Values generally associated with the scientific community (Bernard Barber, Science and the Social Order, Chapter 4).

1. Faith in rationality.

2. Emotional neutrality insofar as it enlarges the scope for exercise of rationality.

3. "Universalism;" all men have morally equal claims to the discovery and possession of rational knowledge.

4. Anti-authoritarianism.

   (Preceding coincide with values of a liberal society in general; following do not.)

5. Community; knowledge is community property (opposed to secrecy).

6. Disinterestedness or other-orientation; serve self by serving others.

7. Values vary depending upon where scientist is working.

D. Problems raised by heavy involvement of government in R&D and the heavy involvement of technical people in government.

1. Freedom to oppose government policy without being ostracized from advisory circles, as happened to those who opposed nuclear policies of Dulles.

2. Competency of non-technical men to judge technical advice and make essentially technical decisions.

3. Competency of technical men to understand the political, social, economic, and psychological aspects surrounding technical matters, and the implications thereof.

4. Maintenance of open channels for all points of view in order to avoid "establishing" a certain viewpoint.

5. Bringing the long-range view into the decision-making process.

6. Necessity of secrecy creates a situation which Snow describes as "closed politics" (C. P. Snow, Science and Government, p. 56) where personal power and personal choice become much more significant that they are in ordinary governmental processes.

    a. Committee politics

    b. Hierarchical politics

    c. Court politics

E. Approaches to lessening the friction and problems between technical and non-technical administrators.

1. C. P. Snow, Science and Government:

    a. Scientists and engineers at all levels of government since the very nature of science--moving in time--requires foresight, whereas administrators are more, by nature, master of the short-term solution to the immediate problem.

    b. Foresight is particularly required in the West because of the existential direction of Western culture. This leaves us without a model of the future.

    c. Admits that scientists in creative periods do not get easily interested in administrative problems.

2. Don K. Price, Government and Science:

    a. System must rely upon generalists with background in general management and general public affairs, and on man who became a generalist after a thorough grounding in science or engineering.

    b. People who rise above specialties are required at top who can keep agencies' interests in line with Administration aims, rather than having agencies under their own stream, going their own way.

F. Observations on science in American government.

1. Executive branch contains mixture of technical and non-technical administrators.

2. Scientific advisory groups operate all various levels in government.

3. Rotation of membership on advisory groups insures wider representation of opinions.

4. Congressional committees have their own professional staffs.

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V. GOVERNMENT INDUSTRY RELATIONS IN AN R&D ATMOSPHERE

A. The problem of maintaining the free enterprise system in a virtually captured industry.

1. Captured industry - extent
Aerospace almost 100 percent
Weapons - virtually 100 percent

2. Regulated Industry
Drugs - FDA
Nuclear - AEC

3. Fee System

a. Categories
Non-profits - discussed in VI
Contracting - discussed in VIII
Incentive - discussed in VIII
Cost plus - discussed in VIII

b. Costs

4. Problem areas

a. Large contracts

(1) 1 or small number of contracts influenced status of contractor.

(2) Nature and size of contracts makes them political.

(3) Failure of contract can affect economy.

(4) Tremendous difficulty in administering large contracts.

b. Non-competitive nature

(1) Unique capability of one or more contractors.

(2) Phasing of R&D into production is often committed by one relatively small study.

c. Management - have management techniques kept pace with technology development?

B. Factors Influencing the Selection of Contractors.

1. Studies - feasibility, etc.

2. Phase research -

3. Production capability - only a very few corporations are, capable in some areas; e.g., airframes, propulsion systems, etc.

4. The nations economy

    a. New types of ventures only possible in periods of expansion of economy

    b. Location of major facilities

        (1) Normal affect

        (2) Congressional reactions

        (3) Concentration near certain geographic centers

            (a) Bodies of water

            (b) Population (or lack of)

            (c) Scientific or educational facilities

    c. Awarding of contracts may involve great distances from the responsible government agency

        (1) Travel

        (2) Time lags

B. Public vs. Private Ownerships

1. Current Government Philosophy - growing on shrinking of Federal system

    a. Political problems in decision to have public or private ownership

    b. Political implications once the decision is made have more repurcussions than those above

2. Benefits in Government ownership

    a. Value to all people

    b. Government may direct all usage

c. Expected lower costs (profit removed) of contracting.

d. Expected lower operation costs, salaries, supplies, etc.

3. Benefits in private ownership.

   a. Maintains free enterprise system.

   b. Competition can provide savings.

   c. Size of Government kept down.

4. Pit falls

   a. Captured industry of few competitors not factor.

   b. Often Government built facilities are run by contractors.

   Examples

   COMSAT

   TVA

   NASA - JPL

   AEC - Brookhaven

VI. GOVERNMENT - UNIVERSITY RELATIONS

A. The growth of research sponsered by the federal government:

1. Early status pre World War II

a. Small grants to a relatively few universities.

b. Grants generally were given to underwrite an individual's specific area of research.

c. No specific emphasis or follow-up on research.

d. Universities did not "live" on grants

2. Impact of World War II

a. Need for top scientific and technical personnel from university.

(1) Only available in universities (no excess of scientists).

(2) No other organizations in R&D business--no historical background in private industry.

(3) Scientists were reluctant to leave atmosphere of university and go to work for government.

b. Rapid technological development

(1) Weapons systems--no longer simply "bigger" but intricate state of the art advances had to be made.

(2) New areas opened by some discoveries.

(3) Combinations--aircraft into missiles, guns into pinpoint delivery of firepower.

c. World situation

(1) Ability of U.S. was challenged by strong power.

(2) Unity of allies created pools of talent.

d. University projects

Example:

Manhattan Project--first U.S. atomic weapon.

3. Impact in 50's and 60's

    a. Continued use of university as source of talent.

    b. Growth of idea to use university as pure research area with government in applied areas and contractors in development.

    c. Continued reluctance of scientists to leave university atmosphere.

        (1) School salary (and supplements) rising.

        (2) Freer atmosphere.

        (3) Away from stigma of government employee.

    d. Large scale entrance of university into contracting.

    Examples:

    University of California - AEC

    M. I. T. - NASA

    Johns-Hopkins - Navy

    California Institute of Technology - NASA

SUMMARY

The university has had considerable influence in all fields of scientific research. Its impact on governmental research is probably greater and will continue to stay that way.

VII. GOVERNMENT RELATIONS WITH NON-PROFIT INSTITUTIONS

A. Introduction

1. Non-profit organizations, as the name implies, perform services for customers for which a profit, in the normal sense, will not be realized. In general, non-profit organizations provide R&D functions for their customers, such as the design, development, and evaluation of complex electronic systems.

2. A non-profit organization can be a university, a private corporation, or even a government agency. Each institution may provide different services but each is reimbursed only for its actual costs. Private corporations will receive a nominal fee negotiated on the basis of need. This fee is intended to be used for facilities and in-house or sponsored research.

3. Some examples of the leading non-profit organizations in terms of government awards are as follows:

   a. Massachusetts Institute of Technology

   b. Aerospace Corporation

   c. Systems Development Corporation

   d. Mitre Corporation

   e. Stanford Research Institute

   f. RAND Corporation

B. The Growth of Non-Profit Institutions

1. Pre-World War II

   a. Universities were the most common non-profit institutions. Their activities generally were basic research into problem areas where practical results in terms of government sponsorship could be gained.

      (1) For example, work in nuclear physics by the Universities of Chicago and California were supported by government grants.

   b. Small research institutes were begun in these pre-war years and performed relatively limited research projects with small staffs. Government sponsorship was relatively limited as well. It took the war to push the need for independent R&D institutions into the forefront.

2. World War II

   a. The abrupt beginning of the war for the U.S. forced military planners to concentrate on tactical and short-term strategical concepts. Little time could be spent in-house on development of long-term and broad-based strategy.

      (1) The establishment of RAND--to meet this need an independent non-profit corporation was set up for the sole purpose of conducting long-range research, and for the development of future military weapons needs. This creation of the military was known as the RAND Corporation.

      (2) RAND has since broadened its capabilities but still retains the "ivory-tower," "think-tank" characteristics its founders envisioned.

   b. RAND was created in a vacuum because there was no corresponding in-house capability in the military to do the kinds of things RAND was to do. The establishment of RAND began the trend of the proliferation of the non-profits.

3. 1945-1954: Mitre and Systems Development Corporation

   a. The need for an early-warning radar system deployed across the North American continent led to the creation of two new private nonprofit institutions, Mitre and Systems Development Corporation.

   b. The creation of the DEW lines and their associated computer and electronic systems again taxed the in-house capabilities of particularly the Air Force.

      (1) <u>Mitre</u> was organized around a group of electronic systems specialists formerly with MIT. The new corporation provided the Air Force with advanced planning and R&D effort in command and control systems. Mitre came up with the basic system plan for the DEW line and wrote the specifications. After contracts had been awarded for the further development and construction of the radar nets, Mitre remained in a technical advisory capacity between the contractors and the Air Force.

      (2) <u>Systems Development Corporation (SDC)</u> was created by the Air Force to perform all the computer programming for the Air Defense Command and to develop new computer systems including SAGE, for our defense control.

c. Both Mitre and SDC departed from the earlier role RAND performed which was a strictly "advanced-think" one. Now, the Air Force in particular, contracted out for detailed technical management advice and let the two corporations do all the systems engineering and technical directión research needed to develop new systems. The non-profits were used now not only for ivory-tower hypothesizing but for the actual technical direction of hardware producing contractors.

4. 1954 to date: Missile Management

a. In 1954 the Air Force was faced with the urgent necessity to develop a complete missile weapons system. Following the now established concept of setting up a third organization outside of the Air Force and outside of the hardware contractor, for technical management purposes, the Air Force encouraged the establishment of an organization within the Ramo-Woolridge Corporation to perform technical supervision with the development of the ICBM.

(1) The new organization, Space Technology Laboratories, (STL), was not a non-profit organization. Consequently, hardware contractors became reluctant to reveal information to a possible competitor and, information which STL needed to properly exercise technical direction was slow in forthcoming.

(2) In 1959, a House Committee recommended that another non-profit corporation be created to handle technical direction of missile systems for the Air Force. This led to the organization of the Aerospace Corporation.

(3) Aerospace, possibly the best example of the government use of private non-profit institutions, performs systems engineering and technical direction (SE/TD) for DOD. A further look at its duties show what all the non-profits are presently doing for DOD:

(a) Systems Engineering Responsibilities include:

1. Review of a hardware contractor's work;

2. Exchange of information or progress and problems;

3. Direction of planning for future work;

4. Modifying, realigning, redirecting, where necessary, a hardware contractor's technical effort.

C. Problems Associated with the use of Non-Profit Organizations

1. In 1964, both the General Accounting Office and a Congressional committee criticized particularly DOD policies with respect to non-profits.

   a. GAO has cited two main areas of concern:

      (1) Salaries: Salaries paid personnel in Aerospace, RAND, etc., were substantially higher than comparable government levels. GAO wondered if such salaries were necessary and justified or were only a way of indirectly paying higher wages for government work.

      (2) Government Functions: GAO is increasingly skeptical of government agencies relinquishing to non-government organizations technical direction and the other activities it consideres traditional government management responsibilities.

   b. The House Armed Services Special Investigations Subcommittee in 1965 specifically denounced the Air Force/Aerospace Corporation relationship and generally the use of non-profits by the government:

      (1) With respect to Air Force use of Aerospace to perform SE/TD, the subcommittee found that:

         (a) Aerospace continually violated government policy in its contract dealings with the Air Force;

         (b) The fee paid Aerospace was used for purposes never intended by the Air Force;

         (c) Inadequate control over reimbursables expenditures existed because Aerospace used its fee to pay for disallowed expenses by the Air Force;

         (d) Management and personnel policies at Aerospace were unreasonable, uneconomical, and unjustifiable.

      (2) The Subcommittee strongly advised the Air Force to re-evaluate its management position with Aerospace and correct these faults. Recommendations were also directed at the entire DOD to further justify the extensive use of the non-profits.

2. Perhaps the real instigator of a change in government philosophy toward non-profit organizations was NASA.

a. From agency inception NASA management insisted that the basic systems engineering and technical direction capability be developed and retained in-house. NASA's general policy is to keep non-competitive awards to non-profit organizations at an absolute minimum.

(1) The main exception to this has been MIT which NASA uses to develop the Apollo guidance and navigation system.

(2) The Jet Propulsion Laboratory, which manages unmanned spaceflight programs for NASA, is also a non-profit institution and is one other exception to the policy. However, JPL was inherited intact from DOD and was not broken up in order to maintain the continuity of the lab missions.

b. The NASA decision not to heavily rely on the non-profits promoted to a significant degree Congressional criticision of the DOD use of non-profits.

D. The Future of Non-Profit Institutions

1. Responding to GAO and Congressional recommendations, DOD decided to institute the following procedures:

a. Air Force relationships with certain non-profits such as System Development Corporation will be placed on a normal service-contractor basis. New work will either be competed or done in-house by Air Force personnel.

b. Restrictive contractual ceilings will be placed on Mitre and Aerospace Corporations to control their size and to provide for more selective assignment of programs to these organizations.

c. More restrictions on fee usages will be developed and implemented.

d. DOD will strive to further develop its in-house managerial capabilities to complement the use of non-profits.

2. It is apparent that the role of the non-profits will be gradually changed in the future. Many of them will undoubtedly seek other areas where their admittedly unique capabilities can be used--state, local governments, educational institutions, etc.

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VIII. PERSONNEL MANAGEMENT IN THE R&D ENVIRONMENT

A. Introduction

1. The growth of R&D has generated a corresponding increase in the need for scientists and engineers.

   a. The number of scientists and engineers in this country has tripled since 1940.

   b. The Committee on the Utilization of Scientific and Engineering Manpower of the National Academy of Science projects the requirement for scientists and engineers by 1975 to be almost double the number today in order to achieve presently defined goals.

2. Government influence on manpower needs for R&D is great.

   a. In terms of numbers, the direct role of the government will have a minor effect on manpower needs.

      (1) Less than fifteen percent of all scientists and engineers are engaged in R&D work for the Government.

      (2) The number of engineers and scientists hired by the government has dropped measurably since 1962.

   b. Government demands, however, will influence the type and quality of personnel needed for the future.

      (1) The establishment of national goals can significantly influence the direction taken in R&D effort. Goals in such areas as:

         (a) Space

         (b) Medicine

         (c) Public health

         (d) Transportation

         (e) Weapons systems

         (f) Peaceful uses of atomic energy

         (g) Sociological applications of R and D talent

      (2) Government activities directly affect the number of scientists and engineers needed.

(a) According to the National Science Foundation, in 1960 the federal government paid for the work of more than three-fifths of all scientists and engineers engaged in R&D.

(b) In 1960, three-fourths of all scientists and engineers engaged in the R&D effort were employed by private industry.

(c) The remainder of the R&D scientists and engineers are employed by educational and other non-profit organizations, whose work is supported by government financed programs.

c. Although not the largest employer, the federal government is effectively the largest consumer of technical manpower.

d. More and more, those engineers directly employed by the government are becoming monitors and managers of programs financed by federal funds.

B. The Recruiting and Selection Process

1. The demand for R and D professionals began during World War II and reached a peak in the mid-fifties when the demand exceeded the supply of graduating scientists and engineers.

2. In the past decade the demand has remained high, challenging employers to develop new and aggressive recruiting techniques, and to offer better salaries and related inducements.

a. Salaries have increased

(1) Industry

(2) Government

b. Fringe benefits packages offered by employers have improved.

(1) Government was once the leader in fringe benefits.

(2) Industry now can match government on most fringe benefits.

(3) Both government and industry R&D employers have developed excellent programs for offering advanced educational opportunities to young scientists and engineers.

(a) Government Employees Training Act of 1958 provides authority to government agencies to sponsor advanced education programs.

(b) To remain competitive, industry offers similar programs.

(4) In-house training programs offered by employers are additional aids in attracting new employees.

c. More aggressive recruiting techniques have been used.

(1) College campus recruiting trips are relied on heavily, but now it is common for both a professional recruiter and a scientist or engineer to represent the employer on campus.

(2) Newspaper and magazine advertisements are used to identify prospective employees.

(3) Recruitment brochures with an emphasis on esthetic quality as well as verbal content to present as good a picture of the employer as possible.

(4) Trips to the employer's facility are paid for where the prospect is treated in a royal manner.

(5) Various training programs have been used to attract students with outstanding potential while in their freshman and sophomore years.

(a) Cooperative Educational Programs

(b) Apprentice Training Programs

(c) Summer Employment Programs

3. The selection process

a. The demand is, of course, highest for the top graduates academically; however, few, if any, scientific or engineering graduates go hungry for lack of some job offer.

b. Federal Civil Service System

(1) Merit principle of selection

(2) Unassembled examination register

C. Federal Agencies and the R&D Scientist or Engineer (From Albert F. Siepert, "Creating the Management Climate for Effective Research in Government Laboratories," in <u>The Management of Scientists</u>, ed. Karl Hill (Boston; Beacon Press, 1964)).

1. Throughout the 1950's there was a gradual deterioration in the government's overall research capability.

   a. The scientific community sensed this trend and accordingly downgraded the prospects of professional satisfaction in a government research position.

   b. A number of excellent men left the public service, and new appointees just out of college were often of a disappointingly lower level of quality.

2. Many factors made serious inroads on the government's scientific capability during this period, but, to summarize, they are:

   a. The greater emphasis the Second Hoover Commission Report (1955) placed on contracting-out work, ~~the~~ that government had traditionally done itself.

   b. The loyalty "witch-burnings" which scientists felt characterized the security programs of some federal agencies in the wake of the McCarthy episodes. Case study - Oppenheimer.

   c. The contraction of program flexibility left in the hands of the responsible in-house lab leadership.

      (1) Spoon-fed financing of increasingly smaller projects.

      (2) Arbitrary limitations on travel to conferences, workshops, and other professional meetings.

      (3) Increasing reliance on part-time external advisors to audit the laboratory program and advise the department or agency leadership what to do about it.

      (4) The relative obsolescence of many government facilities compared to the great progress industry and universities were making in providing modern physical plants for research. Some agencies were fortunate exceptions, such as the National Institutes of Health, certain military labs, and NASA's predecessor, the National Advisory Committee for Aeronautics.

      (5) The increasing gap in salary for research work in government compared with industry and with university scales, plus the availability of outside consultancies.

(a) In the period between World War I and World War II, the starting and medium-grade professional salaries in government were higher than in most industries and universities.

(b) The gap started in 1940, but became serious in the post-war years.

3. Improvements needed or recently made within the government.

a. The Salary Reform Act of 1962 established the policy of "comparability" for salaries of professionals in the government.

b. The Report to the President on Government Contracting for Research and Development (Bell Report, April 1962) devoted a third of its recommendations to executive and legislative steps which would strengthen the research climate within government laboratories. The major recommendations were:

(1) Obtain and maintain really first-rate physical facilities for R&D within the government.

(2) Obtain and retain challenging work assignments rather than passing out all the responsible work to contractor or grantee agencies.

(3) Develop broader allocations of program resources and give the local lab leadership the flexibility to administer these wisely.

(4) Provide fewer echelons of review above the laboratory management, and whenever possible; make reviews of different aspects of the same work on a concurrent, rather than a sequential basis.

(5) Keep salaries, as much as possible, on a reasonably comparable plane with outside competition.

(6) Establish for DOD laboratories some new arrangements for career selection of either civilian or military leadership depending upon their professional qualifications for the particular mission of the installation, rather than continue rotating the top post among military officers as a short-term position for command experience.

(7) Greatly expand the training opportunities for the professional staff under the existing terms of the Government Employees Training Act.

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IX. THE FEDERAL GOVERNMENT PROCUREMENT PROCESS

(NOTE: This chapter has not been developed in great detail because of the extensiveness of the source material provided. References following each heading are to the sources provided.)

A. Introduction

1. History

2. Explanation of terms

3. Sources of procurement law

(Government Contracts, Vol. 1)

B. Basic legal concepts

1. Scope

2. Power to contact

3. Similarities to private contracts

4. Differences between private and governmental contracts

5. Applicability of general principles to government contract

6. Authority of representatives of the government

7. Limitations on the authority of government representatives

8. Implied contracts

(Government Contracts, Vol. 1)

C. Methods of procurement

1. Formal advertising

a. Statutory basis

b. Preparation of invitation for bids

c. Solicitation and submission of bids

d. Rejection of bids

e. Quasi-formally advertised contracts

f. Award of the contract

2. Negotiation

   a. Introduction and history

   b. Comparison with formal advertising

   c. Circumstances permitting negotiation

   d. Determination and findings

3. Coordinated and interdepartmental procurements

   a. Coordinated procurements

   b. Interdepartmental procurement

   (Government Contracts, Vol. 1)

D. Types of Contracts

1. Fixed-price or lump-sum contract

2. Fixed-price contracts providing for redetermination of price

3. Cost reimbursement type contracts

4. Main types used for R and D contracts

   a. Cost-plus-a-fixed-fee

   b. Cost or cost-sharing

   c. Fixed-price, with or without price revision

   d. Cost-plus-award fee

   e. Programmed interdependency incentive method

5. Role of the Source Evaluation Board

   a. Composition and responsibilities

   b. Techniques in evaluating major procurements

   c. Source evaluation procedures

   d. Reports to the source selection officials

   e. Announcement of selection

E. Other considerations

1. Appropriations

a. The budgetary process

b. Congressional limitations on use of appropriations

2. Contract financing

3. Termination of contracts

4. Government furnished equipment, materials, and facilities

(Government Contracts, Vol. 2, 3, 4; NPC 401; NPC 403)

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X. RESOURCES PLANNING FOR R&D PROGRAMS

A. Resources Planning

1. Includes the following

    a. Developing a schedule

    b. Estimating manpower requirements

    c. Estimating funding requirements

2. Problems involved

    a. Undefined specifications

        (1) Beyond state-of-the-art

        (2) Performance criteria not yet determined

    b. High priority placed on early achievement of objective

        (1) Requires rapid buildup of capability

        (2) Sometimes requires parallel R&D programs of certain subsystems

        (3) Sometimes requires parallel development and production programs

    c. Keen competition for large R&D contracts sometimes pressures contractors into making overly optimistic cost and schedule estimates

    d. Lack of historical data to use in preparing estimates

        (1) Changing technology

        (2) Inadequate cost collection methods on previous programs

3. Developing a schedule

    a. Adequately defining work to be done

        (1) Sufficient detail

        (2) Having established test philosophy

    b. Estimating required time for activities

c. Identifying restraints and interfaces

d. Exploring alternate methods

e. Selecting most possible plan

4. Determining manpower requirements

a. Government personnel

(1) Estimating requirements for in-house tasks

(2) Estimating requirements for personnel to supervise and monitor contractors

5. Developing cost estimates

a. Build cost estimate by applying labor, materials, overhead, and fee to manpower requirements

b. Compare with other programs by use of complexity factors and parametric models

B. Recent experience in Resources Planning on large R&D programs:

1. Experience has been that programs took longer and cost more than originally planned, sometimes with changed decreased performance objectives

2. Explanations

a. Highly optimistic "target" schedules established by government

b. Unforeseen difficulties in state-of-the-art advances

c. High rates of design changes because of the following:

(1) Revised performance specifications

(2) Weight reduction programs

(3) Continued improvement ("Goldplating")

(4) Failure in previous designs

(5) Complex interfaces resulting in incompatibilities of systems.

d. Difficulty of effectively managing large-scale effort, especially with a rapid build-up of new personnel

C. Accommodating rapidly fluctuating R&D Programs to the Federal Budgetary System

1. The practice of annual appropriations by Congress enables Executive Branch to achieve some flexibility in that costs for the remainder of the program can be adjusted from original estimates.

2. The inflexibility is that the leadtime on the federal budget is 18 months for the operating levels, so that it is still not possible to include in the budget all of the factors influencing the program during the actual period when the funds will be used.

3. The final adjustments to meet the changing demands of the program may be accomplished in one of two ways:

   a. Reprogramming of funds within a particular agency by obtaining them from programs which are

      (1) Underrunning anticipated costs

      (2) Subject to delayed start to provide funds from ongoing program

   b. Supplemental appropriations from Congress

   c. Examples of these actions in NASA

      (1) Project Mercury received a supplemental appropriation in FY 1960.

      (2) In FY 1963, Project Gemini was aided by funds reprogrammed from Project Apollo when that program's costs failed to materialize as rapidly as possible.

      (3) As a result of lower costs in FY 1965 and FY 1966 in Project Gemini, accomplished by the incentive contract, that project was able to assume its share of Manned Spacecraft Center administrative support costs, thus relieving a burden on Project Apollo.

4. Innovations made by Secretary of Defense McNamara to aid in making these decisions

   a. The planning programming-budgeting approach

      (1) Relates R&D projects to programs (Strategic Retaliatory Force, etc.) to provide better analysis of requirements

(2) R&D projects are planned in "cradle-to-grave" concept

b. Cost-Effectiveness Studies

(1) Attempts to put decisions on a factual basis and eliminate external considerations, such as service rivalries, "pet projects", etc.

(2) Compares systems on basis of effectiveness they will render for certain costs

c. Phased Procurement

(1) Hardware procurement is preceded by feasibility study, preliminary design and final design phases.

(2) Procurement may be stopped without further investment whenever technical problems or excessive costs make the system no longer desireable; or whenever one development in a parallel program clearly becomes more desireable than its competitors.

d. Incentive contracting

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XI. THE ORGANIZATION OF R&D EFFORT

A. Traditional Organization Patterns and Practices

1. Traditional organizational theory (Max Weber, Gulick and Urwick, et al), has its practical application in the organizational structuring of most business firms in the U.S.

   a. The average business is organized around specific functional areas, e.g., manufacturing, engineering, marketing, and administration. Each organizational entity is often semiautonomous.

   b. Most business and government organizations, at least prior to World War II, conducted research work in small labs, removed from the operating levels of the organization.

2. Some of the basic administrative principles on which traditional organization theory is based have their effect on R&D organization. They are as follows:

   a. Specialization of duties

      (1) This principle was first seriously utilized in the U.S. by Frederick W. Taylor and the Scientific Management School of the early twenties.

      (2) Taylor stressed that the work of every person in the organization should be confined as far as possible to the performance of a single leading function. This process usually entails the ever-narrowing of tasks to simple, repetitive routines.

   b. The hierarchy of roles

      (1) The hierarchical structuring of the modern organization is a system of roles--the roles of the superior and of the subordinate--arranged in a chain so that role 1 is subordinate to role 2 and so on.

      (2) The emphasis on the role of the superior has had often deleterious effect on the management of R&D because the functions of scientists and engineers cannot be reduced to simple tasks.

   c. The coordinative principle

      (1) This principle has been stressed in modern organizations to insure that the functional division of labor

operates smoothly. It is tied in with both the scalar processes of limited control spans for top executives and the formal delegation of duties and responsibilities to managers on down the hierarchical line.

(2) The increase in specialization that characterizes present organization, especially in the growth of R&D as a separate function, places strain on the coordinative faculties of an organization. In the past, the hierarchical structure itself facilitated coordination but the R&D process is so dynamic and complex traditional control methods have been found lacking.

3. Traditional organization theory has many other facets but the point to be stressed is that the management of R&D presents certain problems traditional methods often cannot solve. New organizational structures, new management techniques have had to be developed as the R&D industry has grown to its present level.

B. Some further characteristics of R&D

1. We have seen how R&D has grown within this country to a twenty billion dollar per year-plus business.

a. Some of the characteristics of R&D that particularly affect its management are:

(1) Sheer size - The last decades have seen billions upon billions of dollars spent on all types of research with the federal government directly responsible for 70 percent of the total.

(a) In statistical measures the growth of R&D over the years has been exponential. Between 1776 and 1954 a cumulative total of some $40 billion had been spent on R&D.

(b) Within the next decade (1955-1964) more than $102 billion was spent, excluding plant and equipment outlays.

(c) Small businesses account for four-fifths of the 11,800 companies in 1961 reporting R&D expenditures over $100,000.

(2) The need for a multi-disciplinary approach - The demands of R&D for a systematic approach to problem-solving brings together into groups representatives from every scientific and engineering discipline.

So huge is the volume of technical knowledge that specialists in small areas have become completely indispensable.

(3) The need for coordination - From a management standpoint probably the most important characteristic of R&D is the need for effective control and coordination of these innumerable disciplines and study groups that a typical program has. Beyond this is the need to integrate R&D with other functions of the organization to insure that research results are compatible with organization goals and can be translatable into operational products or processes.

b. One other characteristic of R&D today is in the division of total effort. The R&D work process in the last five years has been broken down in the following fashion: Basic Research--10 percent; Applied Research--22 percent; Development--70 percent. The college/university and non-profit institutions are the only sectors where basic and applied research account for the greater percentage of total effort.

2. Definitions of R&D phases and of project management as contrasted to research management are as follows:

a. Basic Research - Research projects which represent original investigation for the advancement of scientific knowledge and which do not have specific commercial objectives, although they may be in fields of present or potential interest to the sponsoring organization.

b. Applied Research - Research projects which represent investigation directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes.

c. Development - Technical activity concerned with non-routine problems which are encountered in translating research findings into product or processes. There can be several phases of development activity as well.

d. Project Management - Management activity encompassing the planning, control supervision, and the engineering, manufacturing and testing required to translate research findings into products or processes. A project organization is usually established after research has been completed and development has begun or is near completion.

3. There are really two types of R&D management: The management of research and the management of large projects and programs evolving from research results. Both types are complementary and interrelated but both are nonetheless unique in terms of pressures and demands placed on the manager.

4. The next chapter centers around the two types--what they are, where they are found in government and industry, how they differ, etc.

    a. Discussion of project management will center on the project manager, his place within the overall organization, and how he manages a typical program.

    b. Discussion of research management will deal with the different organizational structures developed for the conduct of R&D.

XII. THE MANAGEMENT AND CONTROL OF R&D EFFORT

A. The Management of Research

1. Up until a generation ago, most organizations did their research effort with a handful of engineers and scientists. So huge is the volume of scientific knowledge today that specialization of skills is the only way to keep abrest of progress. Research organization mirrors this and unique models of organization have been developed to handle this increase of specialization.

   a. The subject/discipline structure - This organizational structure groups scientific and engineering personnel by appropriate academic disciplines. This is widely used for basic and applied research but not for development. Figure A is a typical example of this structure.

      (1) The basic advantage of this structure is the grouping of specialists with similar training to handle specific problems. Coordination is facilitated and teamwork is stressed. Conversely, it may be difficult to integrate the efforts of a number of these entities.

   b. The product-type structure - This concept groups people of different specialties to work on common problems in the development of specific products or processes. The more basic the research done, the less often it will be organized this particular way. Figure B is an example of this arrangement.

      (1) This structure concentrates needed talents toward the development of specific products the parent organization is interested in.

      (2) Unity of leadership is eased.

      (3) This structure often resembles the project organization in its combination of talents.

   c. The process-type structure - This is essentially a repeat pattern of the above but is used by petro-chemical companies where R&D for the most part is directed toward specific functional processes, e.g., refining, exploration.

   d. The project-problem structure - This structure is used when a specific problem requires the amalgamation of different talents.

(1) This is also similar to the project organization to be discussed later but usually is used only in connection with problems connected with particular production processes where both research and some development will be required. Figure C is a typical example.

e. The stage-phase structure - Since R&D is basically a phased process, this structure is perhaps the most logical.

(1) Under this structure, the research manager controls groups of personnel responsbile for basic research, applied research, and various types of development.

(2) He may also manage a design engineering group which turns the results of the other groups' effort into preliminary designs and specifications.

(3) Work flows through this structure, the efforts of one group becoming the baseline for the activities of another. Figure D shows this structure.

(4) This arrangement is invariably used in addition to the others and often characterizes corporate or headquarters research organization.

2. These different research organization structures are not found in the "pure" state as much as they are found combined and consolidated. Nevertheless, most government and industrial research organizations use these structures and their derivatives to organize their R&D activities. An examination of research organization in two major aerospace companies, Lockheed Aircraft and Grumman, shows how two of these structures are used in actual practice.

a. Lockheed Aircraft Company - Lockheed, the leading DOD contractor in terms of awards in the last four years, is completely decentralized. The entire R&D program is executed by six operating companies with a relatively small corporate group acting as a reviewing agency. Emphasis at Lockheed is heavily on development, prototype fabrication, test and checkout of new systems, etc.

(1) The organization of scientists and engineers is similar throughout the company. R&D is managed by a Chief Engineer or Technical Director who also is responsible for design and project engineering activities. Within the R&D organization there is first a functional breakdown and within that, personnel are grouped on a "subject-discipline" basis.

(2) R&D activities reflect each operating company's specific business objectives and close ties exist between marketing and R&D personnel. Figure E shows R&D organization within the Lockheed Propulsion Company, one of the operating divisions.

b. Grumman Aircraft Engineering Company - Grumman, one of the top NASA prime contractors, unlike Lockheed, controls R&D at the corporate level. The Senior Vice-President for Engineering directs all R&D and project-oriented work and insures that research in particular is tied closely with engineering capabilities of the company. Research findings that appear feasible for further development are passed directly along a sequential line to development and engineering groups. Figure F shows the overall Grumman R&D structure.

(1) The research groups are internally organized on a "subject-discipline" basis while the advanced development group, as shown on the chart, is functionally divided between major company departments on a product-oriented basis.

(2) Tight corporate control of R&D is maintained by a corporate Executive Committee that is responsible for the R&D budget and allocates it to the different R&D groups.

B. Problems of the Research Manager

The research manager faces certain problems all managers face but since his environment is different he must approach them differently.

1. Perhaps his most basic problem is the securing of corporate support in terms of human and financial resources for the research program. R&D is a costly business for a company to be in and the research manager must continually convince top management that it is a necessary business. This is difficult when research results seem to have no immediate commercial applications.

2. Coordination of research - This applies either at the corporate or at the operating level and the more scientific disciplines there are, the more acute the problem can become.

3. The growing friction between the goals of the hierarchy (management) and of the specialist (scientists).

a. Many students of organization theory feel the most significant fall-out from the trend toward specialization has been the growing imbalance between ability and authority--the manager of research has become a generalist and is no longer able to make technical, specialized decisions.

b. The spokesman for this thesis has been Victor Thompson of Illinois Institute of Technology.

c. The research manager is often caught up between the demands of his hierarchical role and his need to keep up with his own specialty.

C. Russian R&D Organization

An interesting comparison can be made of U.S. R&D organization with what we know about Russian organization.

1. All R&D in Russia, is controlled directly by the State. All government organizations participate in one or another aspect of R&D although basic research is the exclusive function of the various science academies.

2. This concentration of R&D decision-making gives the Russians the ability to quickly mobilize scientific talent to attack specific problems.

3. The schematic representation of Soviet R&D organization shown in Figure G shows the pyramidal structure of R&D.

   a. At the apex the Council of Ministers, an appendate of the party, makes general decisions on research directions.

   b. There are three basic sectors within the pyramid:

      (1) The Academy of Science with its concentration on basic research in fundamental sciences;

      (2) Specialized R&D organizations under various state agencies which conduct applied research and development; and

      (3) Institutes for higher education where the entire spectrum of R&D is pursued.

4. In addition to this functional organization, project organizations may be formed on an "ad hoc" basis to attack large, complex programs as, for example, the development and production of the 100 Megaton bomb.

   a. These project units draw from all R&D organizations personnel and other support needed to complete their assigned tasks.

D. Project Management

1. As defined earlier, project management is basically a synthesizing management process which brings together, under one organizational roof, administrative, technical, and other support personnel for the specific purpose of bringing a project from the early stages of development through to operational use. In terms of hardware quantities, at least in the aerospace industry, ten, twelve, or fifteen end items may be the total amount produced, but there are other criteria than quantity that determine the need for a project organization in both government and industrial settings. They are:

    a. Projects requiring significant contributions by two or more functional organizations, e.g., Engineering, Manufacturing, Quality Assurance.

    b. Projects of an advanced nature--advanced studies and development, e.g., the design and development of an advanced electrical power system for long duration space flights.

    c. Projects of a system nature involving systems analysis, development, production, and ancillary items even though the end result may be in production quantities.

    d. Projects where significant pressures of time, money, and performance will exist throughout project life.

2. The growth of the project organization as a unique organizational entity has been quite rapid in the last decade but is still quite recent in terms of history.

    a. The first example of projectization in the U.S. was probably the Manhattan Project of 1942 which managed the development and production of the first atomic bombs.

        (1) General Leslie Groves, commander of the project, was given complete responsibility for coordinating the entire developmental effort, constructing facilities, recruiting manpower, and providing security as well as managing the projects finances.

    b. Utilizing the experience gained from the A-Bomb program, General Bernard Schriever of the Air Force Systems Command in 1954 established a project organization to produce an operational ICBM in the shortest possible time.

        (1) The Atlas missile was subsequently designed, manufactured, tested, and placed into operation by 1959.

3. The project organization in industry can be established one of two ways. It may be an overlay on top of the company's normal functional organization or it may be an organizational entity by itself on a line with or above the functional organizations.

   a. Under the overlay concept the project manager administratively controls only a small staff. He relies on technical and administrative support from the functional organizations. People who work directly on the particular end item the project office is responsible for administratively report to functional managers who can be on a higher organizational level than the project manager. The PM has authority only for project direction (broken line concept) over the organizations producing the end items.

   b. In the other concept the project organization contains within itself all necessary functions such as manufacturing, engineering, testing, contracting, etc.,--all the functions needed to complete the program. The PM in addition usually has direct authority over all other support personnel who are responsible to him for all work done on the project. The PM under this concept reports directly to the cognizant vice-president and with his approval calls on the resources of the entire company when needed.

   c. A functional statement for a typical project office is as follows.

      (1) "Responsible for management and direction of the "X" booster program for missions in support of the "A" and "B" upper stages. Participates in development and/or improvement of the basic vehicle. Project management responsibility includes technical cognizance of advanced research, design and development, fabrication and assembly, test and checkout of complete systems and vehicles, including actual launch. Reviews, evaluates, and coordinates all industrial activities associated with the various contracts. Accomplishes program and scheduling of all phases associated with the booster.

4. By their very nature projects such as Apollo and Polaris pose difficulties for management for which normal experience provides no answers. The project manager in both industry and government is at the focal point of major problem areas and how he handles them has a direct bearing on the success of the project. The areas the PM is most concerned with will be project planning and project control.

a. Project planning - The purpose of planning is simply to assure that the project progresses toward the end objectives of the contract. Planning is a continuous process throughout the life of the project but success usually depends on the validity of the project manager's original operations plan.

(1) Poor project planning leads to the following consequences:

(a) Loss of control due to ineffective budgeting.

(b) Loss of control due to unrealistic scheduling.

(c) Loss of control by not organizing for effective action.

(d) Loss of company profit by too-low estimates, incurring undue risks and insufficient preparation for negotiations.

(e) Loss of morale and incentive on the part of project personnel, resulting in overruns and delinquent deliveries.

(2) Each of the above points are subjects in themselves. The most important thing the project manager will do when formulating his initial operations plan, though, will be how he breaks down the overall job into tasks and subtasks. This breakdown sets the stage for all subsequent planning. The result is called the "Work Breakdown Structure".

(a) The work breakdown structure - The WBS is developed by starting from the highest level of management and progressively breaking work down into smaller and smaller packages until the desired control level is reached and a manageable work unit for further planning and control purposes is developed. Figure H shows a simplified WBS.

<u>1</u>. The actual configuration of the WBS, content, and level of detail varies from project to project depending on complexity of the project, its cost, and the desire of the project's customer (NASA, DOD, etc.)

<u>2</u>. Once the WBS has been established, the project manager designates responsible managers for each discrete work package. The control of budgets, costs, and schedules also depends heavily on the WBS.

b. Project control - The government (the customer) wants to know just three things from the project manager during the life of a project: (1) Will deliveries be made on time; (2) Will the final cost be within the amount contemplated; and, (3) Will the product meet the required performance and reliability standards. The government will want to know, almost to the same depth as project manager, the plans for meeting the delivery, cost, and performance requirements, the actual status of progress versus the plan, and what corrective action is planned or being taken where significant deviations begin to appear.

(1) Control of schedules/progress - In 1958 the Navy in the Polaris program developed a scheduling control tool which is now used throughout the R&D industry. This tool is called the Program Evaluation Review Technique or PERT. PERT is a computerized system and is tied directly to the WBS so, at any point in time, the PM can see schedule progress of the entire job and of the tasks and sub-tasks within it. Using PERT the PM can:

(a) Estimate the time at which each major milestone in the project should be completed.

(b) Predict schedule slippages and estimate their effect on each phase of the project.

(c) Provide the level of schedule detail desired by project, task, and subtask management.

(d) Select the "critical path".

The basic PERT system is continually being improved. Some of the functions PERT networks will be performing in the future are:

(a) Integration of schedule, cost, and technical performance on a common planning and control matrix.

(b) Appraise and validate estimates of time and cost required to develop new aerospace systems.

(c) Evaluate and, perhaps, rate the performance of contractors and government agencies responsible for weapon and space development projects.

(2) Control of budgets - The PM must be able to compare actual expenditures with planned budgets in order to detect deviations and correct them in time.

(a) The WBS identifies the levels to which budgets will be established and from which costs will be reported.

(b) Each sub-division of work should be identified by a code number keyed into the accounting system for automatic processing of all budget data.

(c) The PM establishes detailed budgets, both financial and manpower, for each of the subdivision of work packages, including those in functional organizations not under his direct administrative control. The budgets will be spread by time and require PM concurrence in any deviation from the plan.

(d) The PM must insure that his own budget plan is in consonance with the funding plan of the project's customer. Many government agencies incrementally fund their large contracts which means the industry PM must spread his planned expenditures so as not to exceed his available resources at any point in time.

(3) Control of costs - A strong internal cost management system will have the following objectives:

(a) Establishment of a product-oriented cost management system based on WBS planning and measurement on budget versus cost performance on an automated basis.

(b) Provide a responsible manager-oriented system for establishing program based budgets for functional organization managers and time phasing both financial and manpower allocations with the overall program plan.

(c) Provide executive oriented program cost and progress visibility to management with timely cost/budget inputs, expedient cost problem identification and audited accounting data.

(d) Be easily adaptable to PERT Time/PERT Cost Systems which are customer imposed.

(4) One of the cost management tools by NASA is the "533 Contractor Cost Reporting System." To comply with the requirements of the 533 Report, contractors in some instances have had to upgrade their accounting systems. Some characteristics of the 533 System are as follows:

(a) NASA Field Centers are required to implement the system on all contracts over $500,000 but at their discretion can use them on smaller contracts as well.

(b) Heart of the system is a single reporting format on which contractors show actual cost through the specified reporting period by work package. This report is due monthly. On a quarterly basis, time phased estimates by discrete future fiscal periods through contract completion are provided.

(c) The 533 provides NASA with an integrated picture of past and projected contractor financial and manpower performance. From this cost information the NASA budget for programs is developed.

(d) The 533 system is based on the Work Breakdown Structure agreed upon by NASA and the contractor. In order to be of direct utility in cost management to the contractor as well as to NASA the 533 reporting structure must be compatible with the contractor's own management organization and systems.

(5) Configuration control - Close management control of design changes to hardware is another major necessity of the program control function. Engineers are constantly improving on hardware design and the PM must be able to weigh these possible improvements with schedule and cost constraints. Both industry and government project offices use a Configuration Control Board (CCB), chaired by the PM, to control these changes. Some characteristics of the CCB are:

(a) CCB membership is from each project office organization and from all functional support areas.

(b) Proposed design changes are evaluated for their possible technical improvements and their impact on program costs and schedules.

(c) Official CCB approval is required prior to any actual work done on the proposed change to implement it into the basic design.

(d) Configuration change proposals which are approved by the contractor CCB must still be approved by the customer CCB. Some program offices in NASA allot a million dollars a month to pay for design changes; this amount cannot be exceeded unless the proposed design change is deemed absolutely necessary for program success.

(6) The project control tools listed above and such management techniques as systems engineering and operations analysis must provide the PM with complete project control at all organizational levels in the execution of tasks. To summarize, these tools and techniques are used for:

(a) Development of task activity logic networks which are time-oriented.

(b) Structuring of the work package into logical subdivisions and assigning them to identifiable organizations.

(c) Identification of critical paths in the work process.

(d) Insertion of manpower and cost data into these paths to develop least time/least cost approaches.

(e) Cross-correlation of the project with all other existing projects within the parent organization in terms of competing for the available resources of the business.

(f) Development of these tools and techniques to enable each level of management to plan and control in the appropriate detail.

(g) Use of computer programs to enable the entire R&D operation to utilize these tools in an expedient and meaningful manner.

5. Project techniques in the government differ from those in industry only in the degree of detail. The government PM is concerned with a much broader picture than his counterpart in industry and will leave the detailed planning and control to

the industry PM's. There are, however, some important differences in project organization and management philosophy between government agencies, particularly between DOD and NASA.

a. Each of the three services in DOD have numerous project office organizations. The best example is still the Navy's Special Projects Office (SPO) which managed the Polaris missile development.

(1) SPO was the first government project office to extensively rely on sophisticated management techniques such as PERT. In fact, PERT was specifically developed by SPO and Lockheed Aircraft for the Polaris program. The responsibilities of SPO were quite comprehensive. It was responsible for overseeing the development not only of the missile and its associated systems but coordinated the design and construction of the nuclear powered, missile firing submarines.

b. SPO, supported by Navy line organizations, had the capability inhouse to direct all phases of the Polaris program. Much of this was undoubtedly due to the nuclear submarine management legacy of Admiral Rickover. The Air Force, due to the peculiar characteristics of its own programs and to its limited experience with integrated systems management, organizes its project offices differently from the Navy.

(1) The Air Force project offices, most of which are located administratively in the Systems Command, perform the normal program control functions of budgeting, scheduling, and cost management. In complex programs such as Minuteman and the Manned Orbiting Laboratory, technical management and systems integration responsibilities are contracted out to the various non-profit organizations, as we have seen.

(2) Aerospace Corporation, one of the Air Force's non-profit creations, has responsibility under general AF control for advanced systems analysis, research experimentation, initial systems engineering, technical direction of hardware contractors, and general technical supervision of these contractors in the complete field of Air Force ballistic missiles and space systems. Aerospace has become the technical management arm of Air Force project managers.

c. NASA project management philosophy more closely resembles Navy practice rather than Air Force. Each NASA project organization either has within itself all necessary capabilities, including technical management skills, to completely control its program or can call on all types of support from functional organizations within NASA. The Manned Spacecraft Center's Apollo Spacecraft Program Office (ASPO) is a typical example of a NASA project organization.

(1) ASPO has the responsibility for planning, coordinating, and directing all aspects of the Apollo spacecraft project. The Program Manager has eight organizations reporting directly to him.

(a) Two separate organizations are located at the plants of North American Aviation and Grumman Aircraft Engineering Corporations, the prime Apollo contractors, and the "on-site" representative of the Apollo PM. These offices remain on top of potential schedule, cost, and technical problems that might require immediate NASA attention.

(b) The Mission Operations Division defines flight test requirements and establishes mission ground rules consistent with crew safety, comfort, etc.

(c) The Lunar Module Checkout and Test Division is directly responsible for LM production and ground test programs. It monitors the progress of each spacecraft from initial manufacturing through checkout to launch.

(d) The Command and Service Module Checkout and Test Division concerns itself with the C&SM in the same fashion as the above division controls LM production.

(e) The Systems Engineering Division controls and coordinates the designs, specification, and development of spacecraft systems. This division defines and specifies system interfaces.

(f) Reliability, Quality, and Test Division develops and monitors policies and procedures for assuring the reliability and quality of all systems and components--an important function in manned spaceflight.

(g) Program Control Division develops budgeting and scheduling plans for the project. The PERT function is located here.

(2) The ASPO PM receives further technical support in the management of spacecraft subsystems, e.g., the Propulsion System. Groups of engineers manage each subsystem and are directly responsible for them to the PM.

(3) NASA management philosophy has been that the basic systems engineering and technical decision making capability must be retained in-house. Each NASA program office retains the capability to make technical decisions, relying on inputs from a number of sources, both in and out-of-house.

6. Project management in practice may be something less than perfect only because it is still a relatively new phenomenon. The sophisticated, computerized program control techniques are in a continual improvement process. Indeed, hardly a month passes without a new article in a management magazine citing another breakthrough in project management techniques.

7. The project manager, particularly in industry, still has some major remaining problems that must be solved. They are:

   a. The need for a degree of authority corresponding to his responsibilities. This problem is not as acute in large programs such as Apollo as it is in smaller ones where a number of project organizations might exist side by side in a company.

   b. A more workable, semi-contractural agreement between the PM and the various functional organizations within the company.

   c. How to measure technical accomplishments relative to time and money spent. Some progress has been made in adapting the PERT system to do this.

FIGURE A

THE SUBJECT-DISCIPLINE STRUCTURE

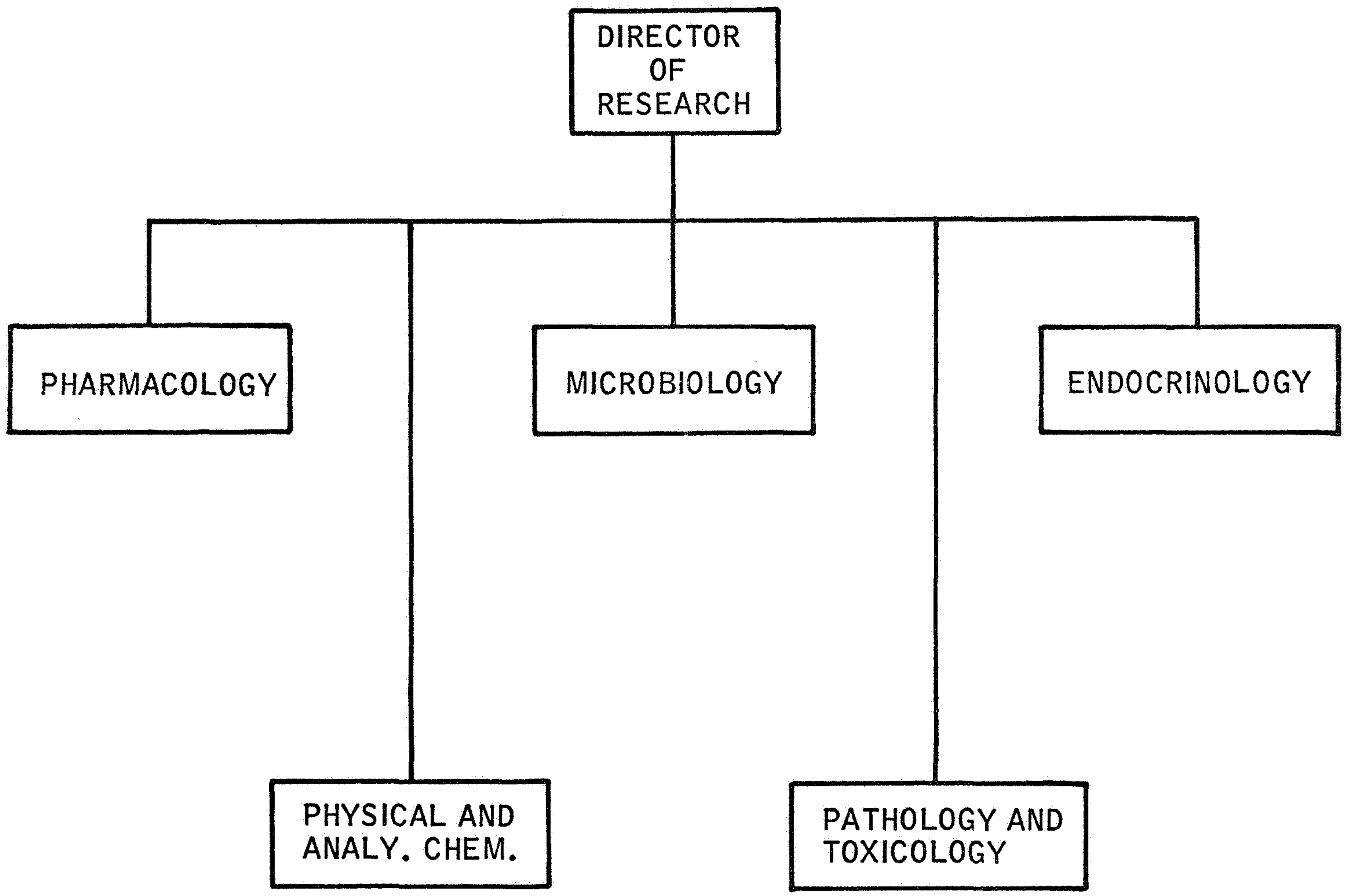


FIGURE B

THE PRODUCT-TYPE STRUCTURE

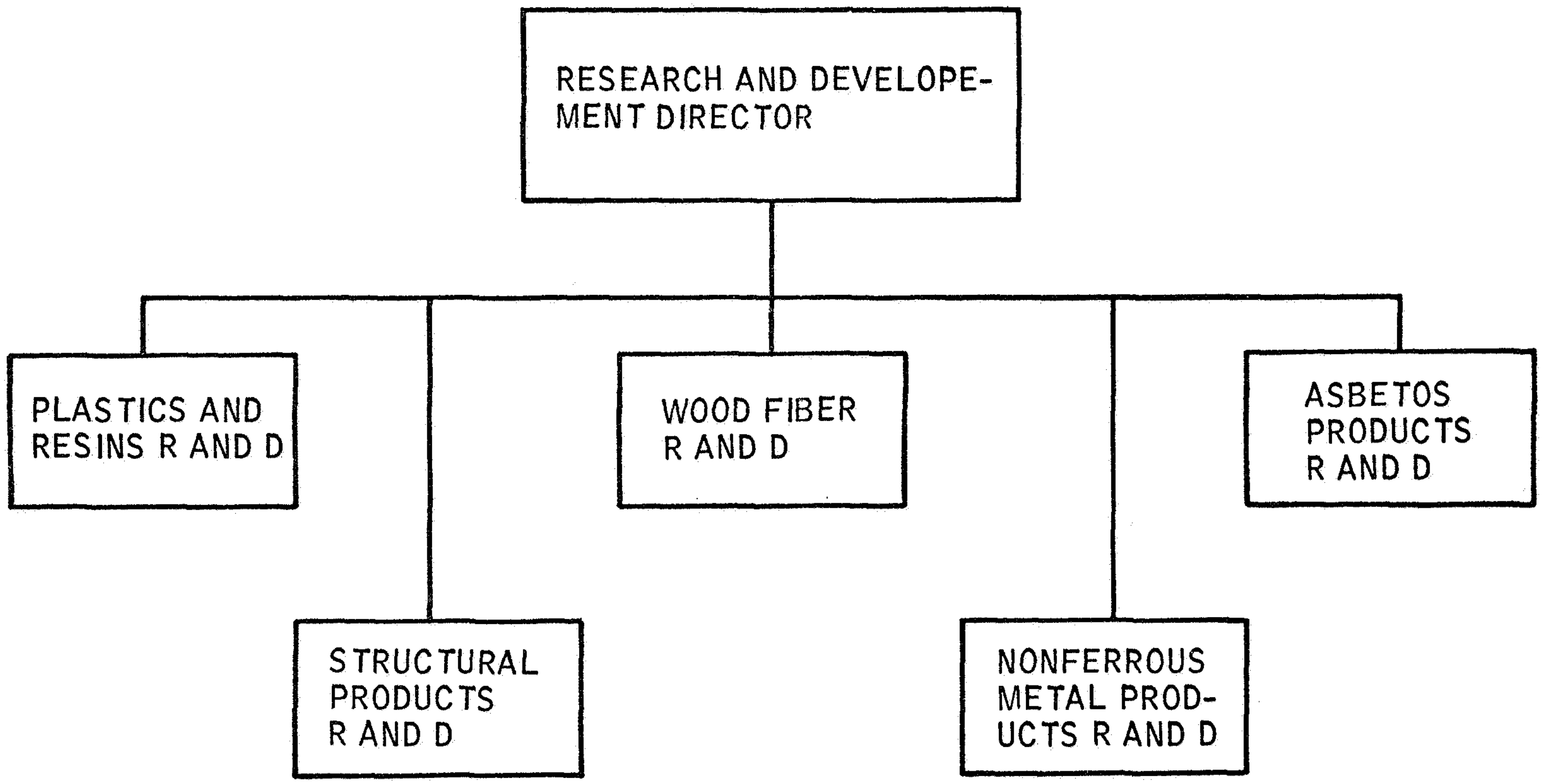


FIGURE C

THE PROJECT-PROBLEM STRUCTURE

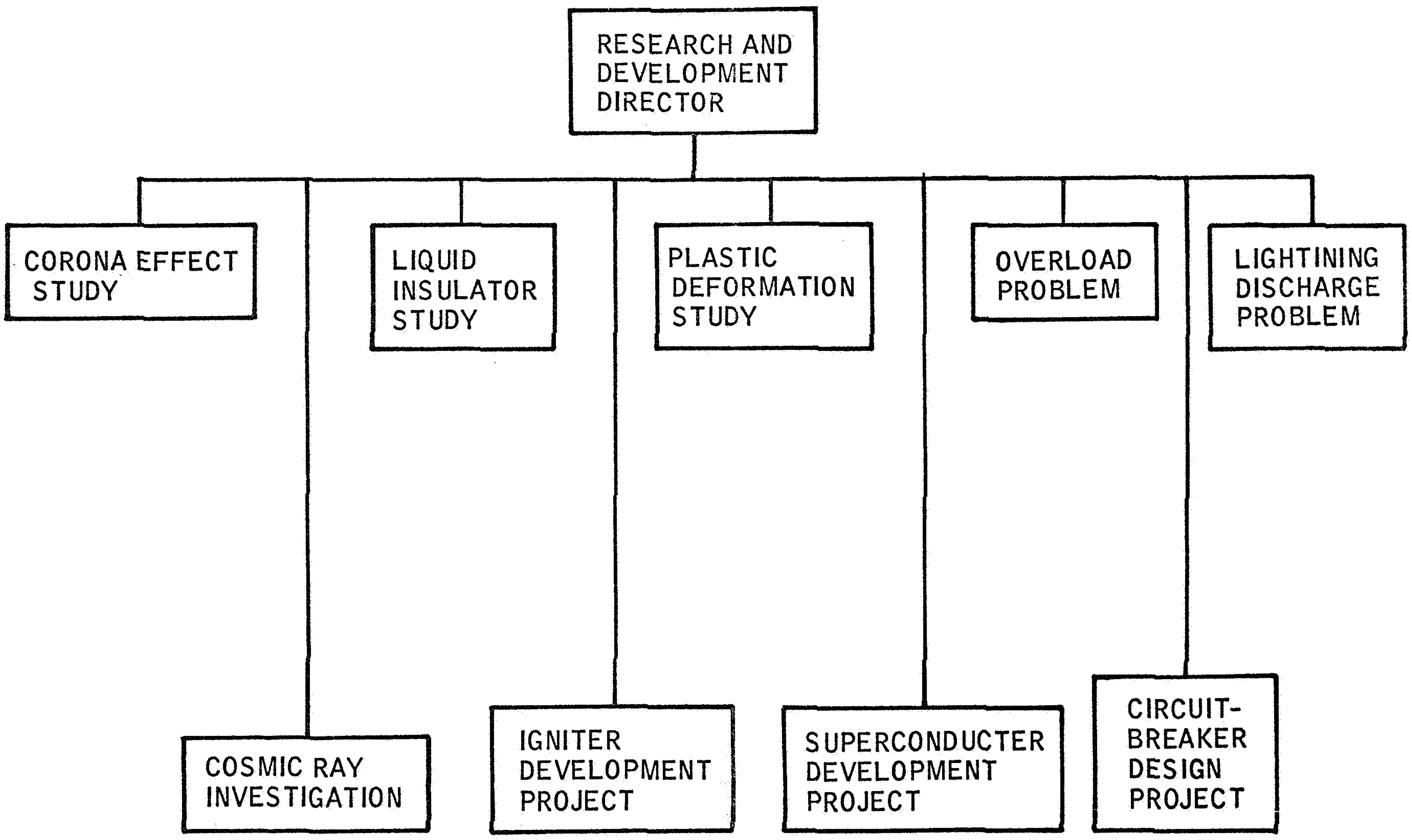


FIGURE D

THE STAGE-PHASE STRUCTURE

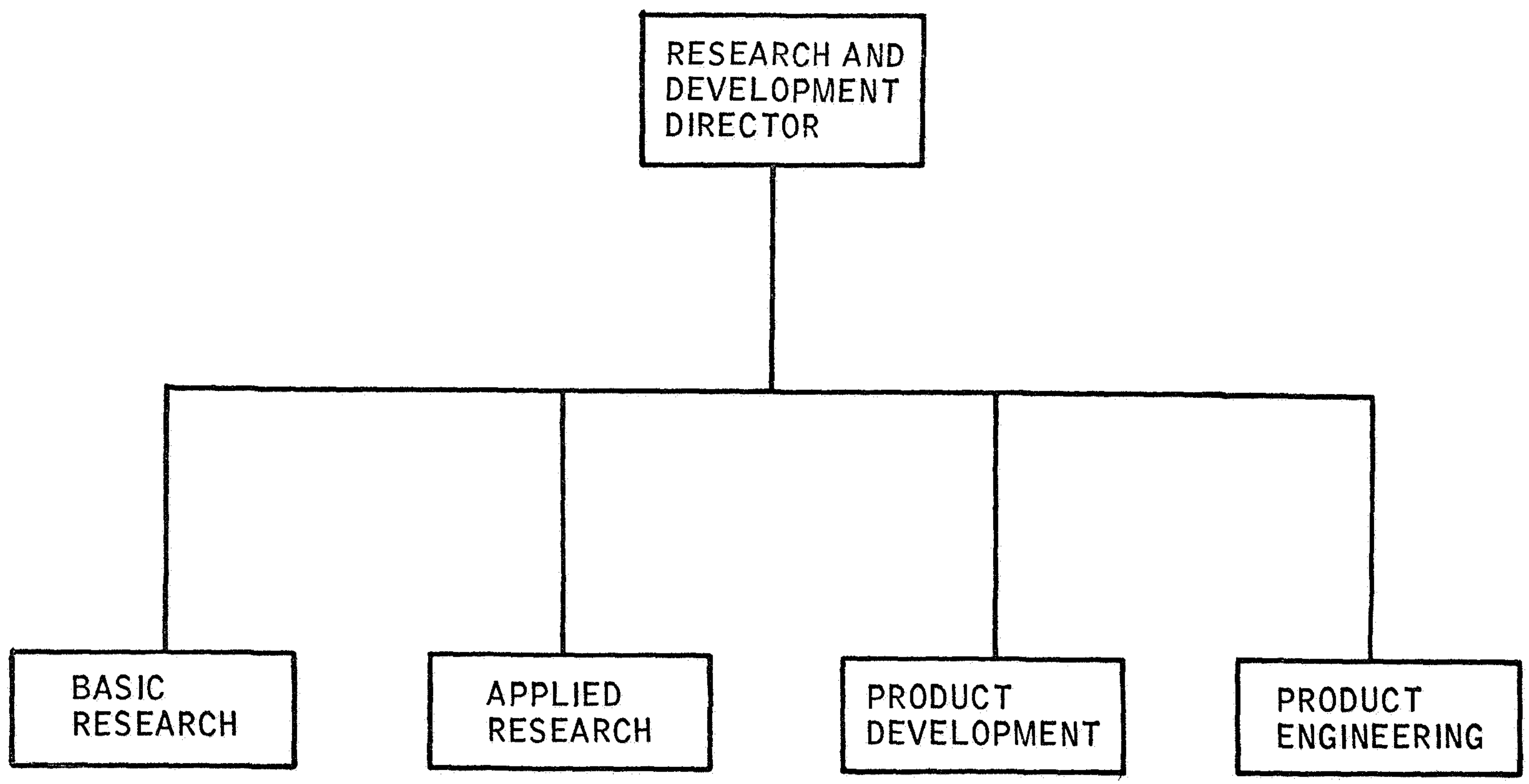
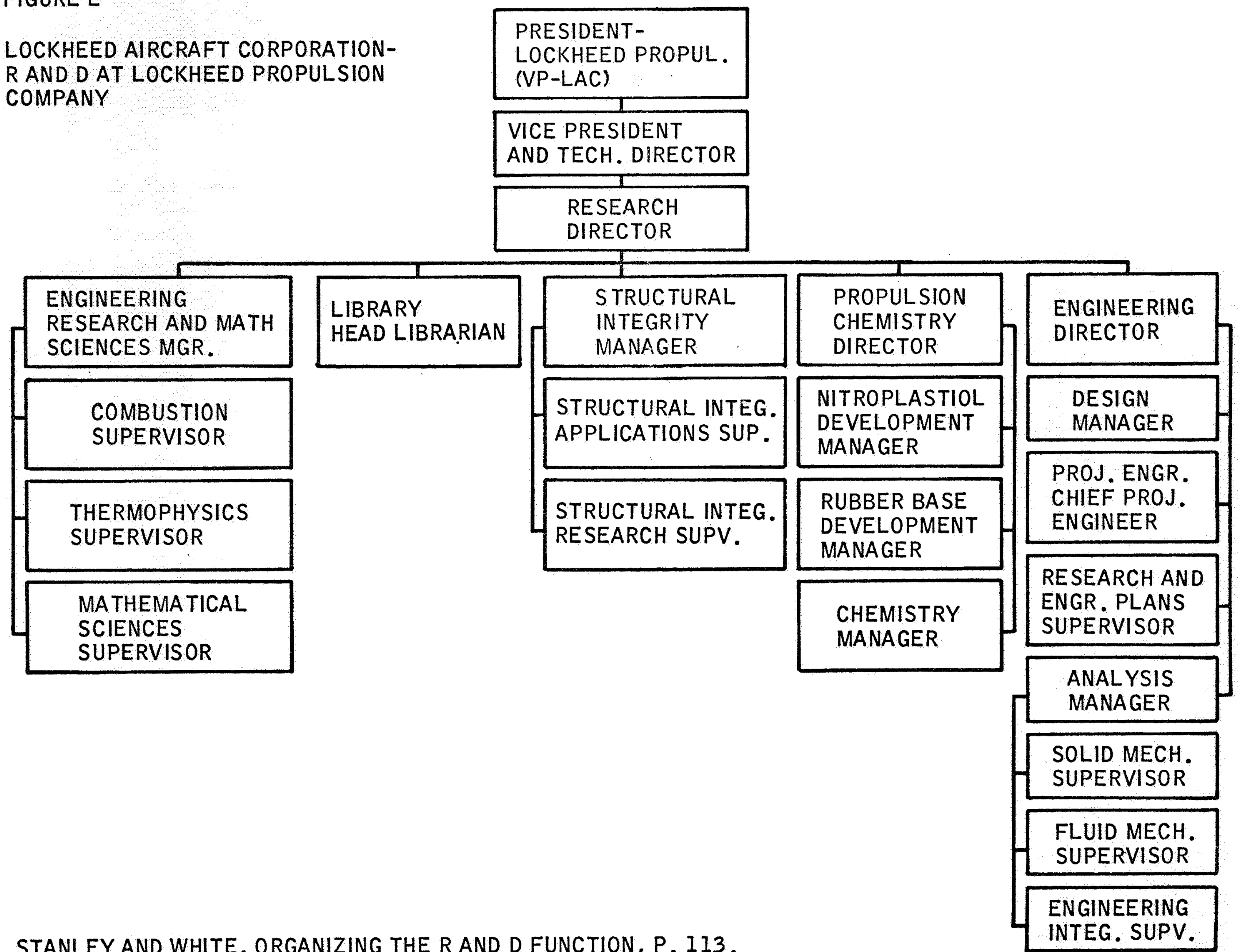


FIGURE E

LOCKHEED AIRCRAFT CORPORATION-
R AND D AT LOCKHEED PROPULSION
COMPANY



STANLEY AND WHITE, ORGANIZING THE R AND D FUNCTION, P. 113.

FIGURE F

GRUMMAN AIRCRAFT ENGINEERING CORPORATION, RESEARCH AND DEVELOPMENT

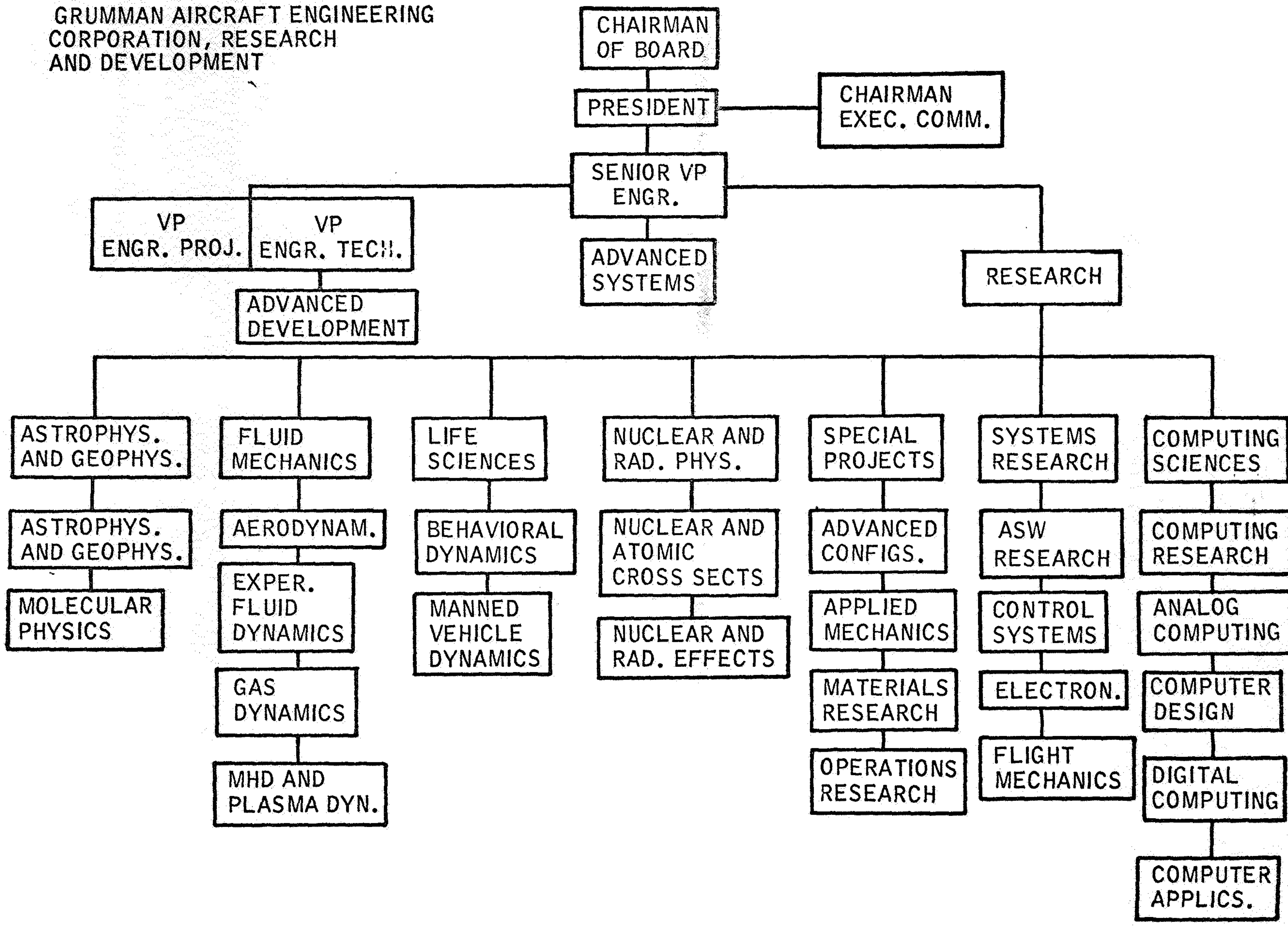
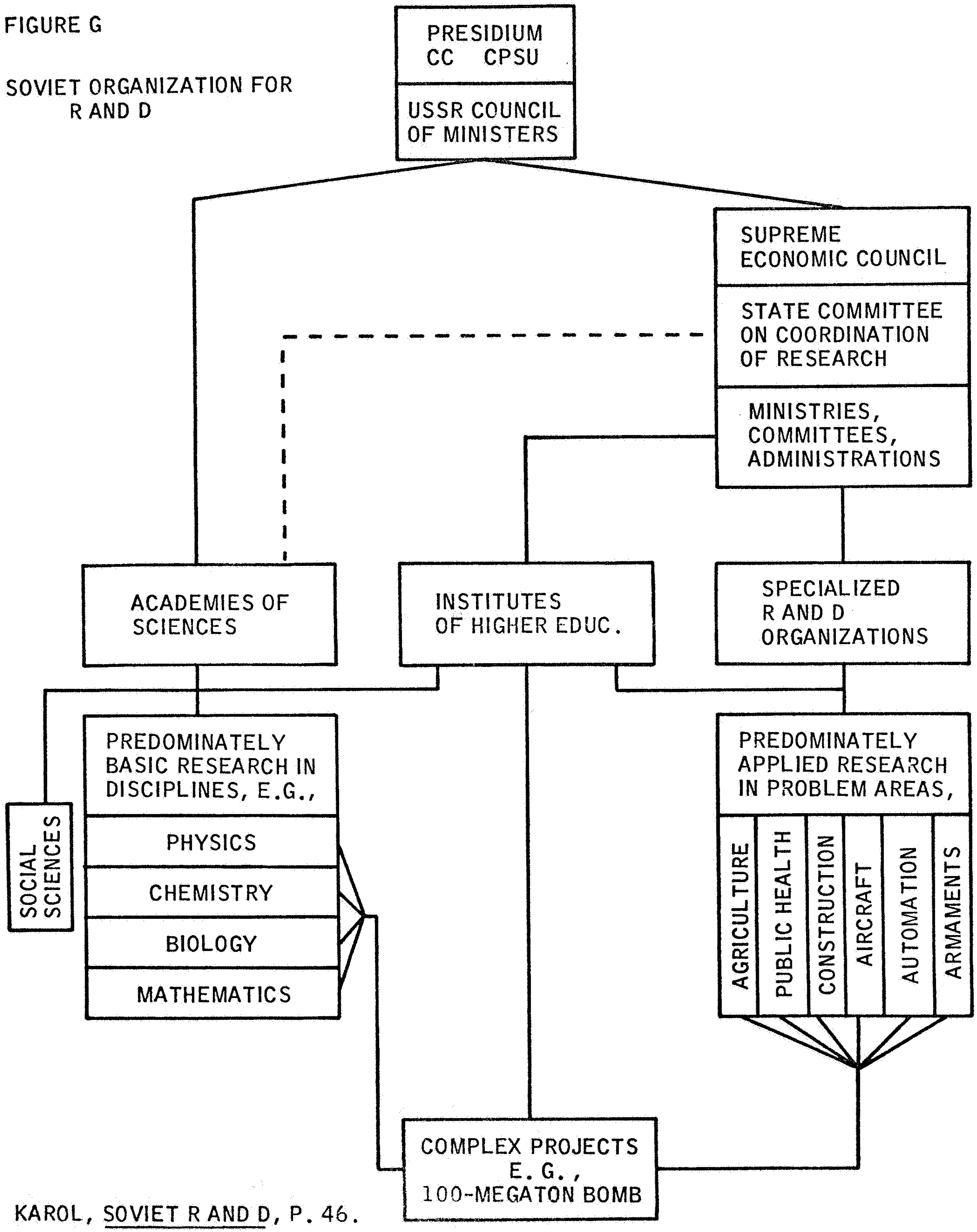


FIGURE G

SOVIET ORGANIZATION FOR
R AND D



KAROL, <u>SOVIET R AND D</u>, P. 46.

FIGURE H
SIMPLIFIED WORK BREAKDOWN STRUCTURE